

# INDUSTRY SEGMENT PROFILE

SIC 3728

***Aircraft Parts and Auxiliary  
Equipment, nec***

EPRI Center for Materials Fabrication

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Thumbnail Sketch of Typical Establishment
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**SIC 3728 Aircraft Equipment, nec**

<b>Median No. of Employees*</b>	106.0
<b>Annual Shipments</b>	\$16.2 Million
<b>Median Annual Electricity Consumption</b>	3.3 Million kWh
<b>Electricity Opportunities</b>	Electrotechnologies to replace casting, heat treating and coating processes to reduce environmental emissions
<b>Technology Trend</b>	Technologies to increase the life of aging aircraft, provide advanced materials for performance, and switch to environmentally sensitive coatings processes.
<b>Industry Issues</b>	Very cyclical business. Aircraft oligopoly (Boeing and Airbus) controls the standards that aircraft parts suppliers must meet.

## Industry Characteristics

This industry is made up of companies manufacturing the following products:

- ♦ Aircraft body assemblies and parts.
- ♦ Aircraft power transmission equipment.
- ♦ Aircraft propeller parts.
- ♦ Aircraft brake expanders.
- ♦ Alighting assemblies (landing gear).
- ♦ Aircraft brakes.
- ♦ Aircraft fuel tanks.
- ♦ Aircraft wheels.
- ♦ Aircraft elevators, etc.

The segment does not cover companies that are primarily engaged in manufacturing:

- ♦ Complete aircraft.
- ♦ Aircraft engines and parts.
- ♦ Aeronautical instruments.
- ♦ Aircraft engine electrical (aeronautical electrical) equipment.
- ♦ Guided missile and space vehicle parts and auxiliary equipment.
- ♦ Primarily engaged in research and development on aircraft parts on a contract or fee basis.

The major industries supplied products from the aircraft equipment and parts industry are listed below (in order of importance):

- ♦ Aircraft manufacturing and assembly industry.
- ♦ Federal Government (Department of Defense).
- ♦ Space vehicle and missile manufacturing industry.
- ♦ Air transportation industry.

No dominant category of parts or assemblies supplied exists because of the great number of parts involved in aircraft assembly.

- ♦ More than 65% lack a defined description and are classified as "other".
- ♦ Aircraft landing gear total 6.8% of industry shipments. The split between civilian and military landing gear is 58% for civilian and 42% for military applications.

- ♦ Aircraft hydraulic and pneumatic assemblies comprise 6.7% of total industry shipments. The split between civilian and military hydraulic and pneumatic assemblies is 78% for civilian and 22% for military applications.
- ♦ Aircraft power transmission equipment comprises 6.1% of total industry shipments. The split between civilian and military power transmission equipment is 56% for civilian and 44% for military applications.
- ♦ Research and development on aircraft parts make up 5.9% of total industry shipments.
- ♦ Other aircraft subassemblies for US civilian aircraft comprise 50.0% of total industry shipments.
- ♦ Other aircraft subassemblies for US military aircraft comprise 17.8% of total industry shipments.

The aircraft equipment industry is dominated by four large companies – BF Goodrich Co/ Coltec Industries, Sundstrand Corp, Simmonds Precision Products and Lucas Aerospace.

- ♦ BF Goodrich Co and Coltec Industries merged July 12, 1999.

This \$17.3 billion industry is geographically concentrated in California and Washington, though Texas, Kansas and Connecticut also have a significant presence.

- ♦ California alone accounts for nearly 30% of US shipment value.
- ♦ California, Washington, Texas, Kansas and Connecticut together account for nearly 65% of US shipment value and 70% of US employment.

There are approximately 1121 manufacturing facilities in the U.S.

41% of these facilities employ 20 or more employees; 15.5% have 100 or more employees.

The average wage rate for production workers manufacturing aircraft equipment is \$19.98 per hour, 57.5% higher than the average wage rate for all U.S. hourly manufacturing plant workers (\$12.68 per hour).

The production of aircraft equipment is similar in energy intensity to other metal fabrication industries

- ♦ Total establishments in this industry purchased 3526.3 million kWh of electricity in 1996.
- ♦ The cost of purchased electricity was \$195.5 million.
- ♦ In the same year, the cost of purchased fuels was \$43.7 million.
- ♦ The consumption of electricity, on average, was 0.32kWh per dollar of value added. The average for metal fabricators in SIC 34 is 0.33kWh/\$VA).

National Statistics
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Figure 1. National Data of End-Product Classifications, 1992

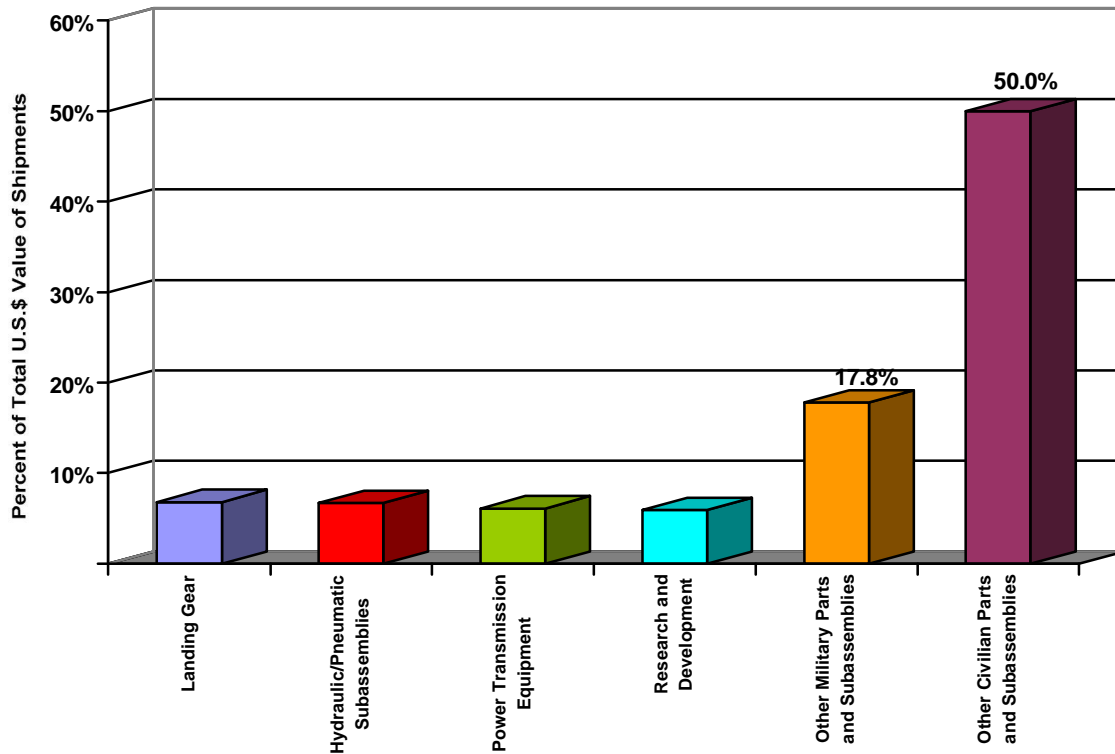


Table 1. Trends for SIC 3728 Aircraft Equipment, nec

	1992	1993	1994	1995	1996
Industry Shipments (\$Millions)	19,834.6	18,264.3	17,048.6	16,847.6	17,311.8
Employment (1000s)	165.3	139.4	121.6	116.3	113.4
New Capital Expenditures (\$Millions)	1,132.1	713.1	656.2	673.0	916.1
Electricity Purchased (Millions kWh)	3,557.9	3,346.1	3,480.1	3,306.2	3,526.3
Full Production Capacity Utilization Rate (5)	88	70	67	59	67

**Table 2. Top Ten U.S. Companies Ranked by Revenues**

<b>Firm</b>	<b>Headquarters Location</b>	<b>1997 Sales (\$Millions)</b>
BF Goodrich Co.	Richfield, OH	3,373
Sundstrand Corp.	Rockford, IL	1,752
Coltec Industries Inc.	Charlotte, NC	1,315
Simmonds Precision Prod. Inc.	Akron, OH	1,000
Lucas Aerospace Inc.	Arlington, VA	825
B/E Aerospace Inc.	Wellington, FL	412
Triumph Group Inc.	Wayne, PA	401
Aviall Inc.	Dallas, TX	400
Aerostructures Corp.	Nashville, TN	362
K&F Industries	New York, NY	265

In July 1999, BF Goodrich Co and Coltec Industries merged;

- ♦ 1998 revenues reached \$ 4 billion for BF Goodrich and \$1.5 billion for Coltec.
- ♦ Concurrent with the merger, BF Goodrich moved its corporate and aerospace headquarters to Charlotte, North Carolina, where Coltec had its headquarters.
- ♦ Simmonds Precision Prod. Inc is a subsidiary of BF Goodrich Co.

Industry Data by State (1992)
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**Table 3. Industry Data by State**

State	Establishments	Value of Shipments (\$Millions)	% of U.S. Shipments
California	292	5,710.0	28.8
Washington	118	2,054.2	10.4
Texas	83	1,626.1	8.2
Kansas	70	n.a.	n.a.
Connecticut	56	1,385.3	7.0
Ohio	42	n.a.	n.a.
New York	54	589.7	3.0
Oklahoma	30	456.0	2.3
Arizona	26	n.a.	n.a.
Illinois	11	n.a.	n.a.
Sub-total	782		
<b>Total U.S.</b>	<b>1121</b>	<b>19,834.6</b>	<b>100.0</b>

Source: 1992 Census Data

## Competitive Threats

The \$48.8 billion global commercial passenger segment of the civilian aircraft industry is currently a “duopoly”, consisting of the Boeing company (55% market share) and Airbus Industries (45% market share), a four-company European consortium. The aircraft parts and auxiliary equipment segment contained in SIC 3728 is largely controlled by these industry giants.

The parts business requires a high degree of service and local interaction with the US airlines companies. Parts are more customized, and are not the high volume commodity type of parts found in the automotive sector, for example. The ability for foreign competitors to move in without a strong local manufacturing presence is minimized.

Deregulation of the global airline industry (US deregulation in 1978 and European deregulation in 1997) has increased domestic and global airline competition, sparking fare wars and forcing airlines to become more cost-conscious.

- ♦ Airlines have become much more concerned with an aircraft’s operating costs, as well as initial price.
- ♦ Airlines are streamlining their fleets to obtain commonality of engines, systems, maintenance and other operations.
- ♦ Commercial airplanes have become more like commodity products, which compete on price and operating cost, as opposed to performance characteristics.

According to industry consultant Avitas, global passenger air traffic grew at an average annual rate of 4.6% between 1987 and 1997. In 1998 and 1999, however, growth in global air traffic declined 2.4%, and could slip another 2.3% in 2000.

- ♦ With airline capacity expected to climb 4.0% in 2000, outpacing passenger air traffic growth, there is a high probability that both the airlines and aircraft manufacturers could experience turbulence ahead.

The market-share battle between Boeing and Airbus will impact the parts industry in SIC 3728.

- ♦ If China continues to favor European producers, Airbus will have an advantage in the world’s single fastest-growing market.
- ♦ The success of Airbus will depend in large part on the success of its major initiative to restructure and privatize the multinational consortium.
- ♦ A significant threat to Boeing and its domestic suppliers is a dollar that becomes too strong relative to other currencies, particularly the Euro currency.

The aircraft equipment industry has companies with manufacturing and service facilities located abroad.

- ♦ Products and services are marketed through sales subsidiaries and distributors in a number of foreign countries.
- ♦ Currency fluctuations, tariffs and similar import limitations, price controls and labor regulations can affect foreign competition.
- ♦ Other potential limitations include expropriation, nationalization, restrictions on foreign investments or their transfers, and additional political and economic risks.
  - Boeing is currently restricted by the US government from providing aircraft to Libya, which recently ordered 25 jet aircraft from Airbus.
- ♦ The transfer of funds from foreign operations could be impaired by the unavailability of dollar exchange or other restrictive regulations that foreign governments could enact.

Labor negotiations and potential strikes by the various unions representing the aerospace industry employees are a constant threat.

- ♦ The February-March 2000 strike by Boeing engineers cut monthly production from 42 to 25 planes, in addition to delaying other year 2000 shipments.

## Investment Issues

The industry, which generated \$17.3 billion in revenues in 1996, is capital intensive compared to other manufacturing industries.

- ♦ \$6.2 billion are invested in machinery and equipment assets.
  - Machinery and equipment assets for most manufacturing industries averages between 25 and 50% of annual shipments.
- ♦ \$2.7 billion are invested in building and structure assets.
- ♦ Thus, there is \$1 invested for every \$1.95 in shipments.

After lean years in the early 1990's, new capital expenditures have been increasing since 1995 with the largest increase reached in 1996 (35% greater than expenditures in 1995).

- ♦ A total of \$916.1 million was reinvested in new capital equipment and buildings in 1996.
- ♦ This investment amounted to 5.3% of shipments.

## National Trends

Shipments of aircraft parts and auxiliary equipment are less cyclical than industry shipments of aircraft as a whole, because there are a large number of existing aircraft that need to be maintained.

- ♦ Maintenance programs are less affected by government expenditures and general economic conditions than new aircraft sales, except to the extent that significant numbers of aircraft are added or retired.
- ♦ The industry had a 10% increase in shipments from 1987 to 1992 while employment decreased 12%. From 1992 to 1996 the shipments decreased about 9% and employment dropped 6.9%.

The number of establishments remained flat between 1992 and 1999, following an increase of 10% from 1987 to 1121 establishments.

- ♦ From 1987 to 1992, the number of establishments with 1 to 20 employees increased from 540 to 660, an increase of 22.2%.

Boeing experienced significant production bottlenecks in 1997 due to large increases in aircraft orders.

- ♦ They were forced to rely on subcontractors and parts manufacturers to help alleviate their capacity problems.
- ♦ The cycle trended slightly downward after the boom year in 1997, but is expected to recover in 2000 through 2002.

Airline traffic is expected to remain strong since the general economy is healthy and business and leisure travel have become more affordable.

The demand for aftermarket replacement parts should remain steady as airlines continue to retrofit older airplanes to meet FAA Stage III noise regulations and to comply with stricter safety guidelines.

The aerospace market is shifting from a government-dominated market to one driven primarily by commercial customers. In 1987 military aircraft represented 57% of the total value of products shipments, civilian aircraft represented 43%. In 1992, military aircraft represented 34% and civilian aircraft rose to 66%.

- ♦ In March 2000, The Lockheed Martin Corporation, the world's number 1 military contractor, signed a contract worth \$6.4 billion to sell 80 advanced F-16 fighter jets to the United Arab Emirate.

Both Boeing and Airbus have forecasted commercial aircraft demand at about 16,000 jets over the next 20 years.

In 1998, Boeing formed the Aircraft Creation Process Strategy (ACPS) to provide greater reliance on preferred and sole-source suppliers for major equipment on airplane lines.

- ♦ Facilitate rapid time-to-market periods, as well as creation of an agile supplier “web”.
- ♦ Continuous development of ready-to-apply products, processes and technologies by “sole-
  - Three tiers of suppliers were tied together using a single source of product data, based at Boeing.
  - Suppliers were required to acquire sophisticated computer aided design and manufacturing systems to encourage easy flow of 3D, digitally defined data between program entities.
- ♦ Suppliers were tasked with providing integrated assemblies or systems based on Boeing specifications and cost targets. Suppliers had a larger responsibility for work statements, including managing other suppliers
- ♦ As part of its ACPS push, Boeing planned to form a chief technology office with a set strategy, objectives, and defined technology needs. Concepts would be developed, proven and certified, then placed on a “virtual bookshelf “ ready for the market.
  - Boeing and its supplier partners would share bookshelf knowledge, with protection of proprietary data. The job of a supplier was to keep the shelf “refreshed”.
  - Boeing indicated that most program partners would be selected from the bookshelf.
- ♦ A similar chief configuration office would manage a steady flow of new aircraft configurations. Key strategies would include reuse of components and reducing parts counts with integrated, monolithic structures.
- ♦ ACPS also would have a major effect on Boeing aircraft marketing. A new selling process would be aimed at designing “to a market” while selling to the individual customer. Aircraft catalog options would be reduced with financial incentives to limit aircraft customization.

Boeing, Raytheon and Lockheed Martin announced an Internet trading exchange for aerospace parts in March, 2000.

- ♦ Aerospace and defense companies will bid, buy and auction original airplane parts and replacement parts.
- ♦ The exchange is in the planning stages, but will likely begin with commodity type parts.

Parts shipments are influenced by commercial aircraft deliveries, which increased from 1996 to 1999, but are expected to decline beginning in the year 2000. Projections are shown in Table 4.

**Table 4. Total Worldwide Commercial Aircraft Deliveries**

<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
<b>399</b>	<b>559</b>	<b>788</b>	<b>910</b>	<b>720</b>	<b>642</b>	<b>623</b>
	<b>+40%</b>	<b>+40%</b>	<b>+16%</b>	<b>-21%</b>	<b>-11%</b>	<b>-3%</b>

*Source: Forecast's Source For 1999 And 2000: Boeing And Airbus*

Jet aircraft orders have been much more cyclical than aircraft deliveries, and are expected to increase for the year 2000 through year 2002 as shown in Table 5.

**Table 5. Jet Aircraft Orders**

<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>
<b>150</b>	<b>508</b>	<b>913</b>	<b>989</b>	<b>859</b>	<b>223</b>	<b>339</b>	<b>408</b>	<b>654</b>
	<b>+240%</b>	<b>+80%</b>	<b>+8.3%</b>	<b>-13.1%</b>	<b>-74%</b>	<b>+52%</b>	<b>+20%</b>	<b>+60%</b>

*Forecast's Source For 2001 And 2002: Avitas*

## Market Structure

This industry is comprised 1,121 establishments and 1,030 companies according to the 1996 Census.

- ♦ 58.9% of manufacturers employ less than 20 people.
- ♦ 15.5% of the total employ 100 or more employees.
- ♦ The top 20 companies account for 75.2% of shipments and 68.4% of the employees.
- ♦ The bottom line is that the market power is very concentrated within the top level of this oligopoly, despite the large numbers of small companies.
- ♦ The six top companies supply 54.5% of total U.S. shipments.

**Table 6. Number of Establishments by Employment, 1996**

<b>Number of Employees</b>	<b>1-19</b>	<b>20-99</b>	<b>100+</b>	<b>Totals</b>
SIC 3728 Establishments	<b>660</b>	<b>286</b>	<b>175</b>	<b>1,587</b>
Percentage of Total	<b>58.9%</b>	<b>25.5%</b>	<b>15.5%</b>	<b>100%</b>

*Source: Census Data*

- ♦ Median employment is 106 people per establishment.
- ♦ BF Goodrich accounted for approximately 20% of total value of shipments in 1997. Sundstrand Aerospace accounted for about 18%.
- ♦ Further consolidation within the aircraft parts and equipment industry has resulted in a more concentrated oligopoly.

## Summary of Industry Issues

The aircraft equipment industry has long-term development projects, heavy research & development (R&D) expenses and capital expenditures. Barriers to entry into this business are extremely high.

- ♦ Development costs, large ongoing capital expenditure requirements, and airline customer's desire for cost efficient fleet commonality, all make it extremely difficult for upstart companies to break into the aircraft equipment manufacturing business.

Demand for large commercial aircraft is primarily driven by airlines' profitability and long term fleet planning, which is based on air traffic demand forecasts, route structure, age of existing aircraft and financial projections.

Airline industry profits have been extremely volatile since deregulation in 1978, as intense competition has led to periodic price wars.

- ♦ The latest downturn occurred in the early 1990s, when the airline industry suffered enormous losses and several major airlines filed for bankruptcy protection.
- ♦ After losing \$12 billion from 1990 through 1992, the industry returned to profitability in 1993.
- ♦ Operating profits of the major U.S. airlines subsequently soared to record levels, reaching \$8 billion in 1998, according to Air Transport Association statistics.

As of the second quarter of 1999, the world backlog of orders for commercial jet aircraft totaled 2970, with 1686 aircraft (57%) ordered by U.S. customers and 1284 (43%) ordered by overseas customers. These totals include 1577 aircraft (53%) ordered from Boeing and 1393 (47%) orders placed with Airbus.

- ♦ Despite the Asian financial downturn and economic problems in Latin America in the late 1990's, there was sufficient backlog to keep parts suppliers busy.

Governmental regulations are a significant issue for all manufacturing concerns, including the airline equipment industry.

- ♦ The Occupational Safety and Health Administration (OSHA) and the American National Standard's Institute (ANSI) are both working on new standards to prevent injuries related to ergonomics, usually defined as musculoskeletal or cumulative trauma disorders.
  - Manufacturers of aircraft parts and equipment have less total OSHA cases and lost work day incidents (LWDI) from injuries and illnesses as the overall to which it belongs - SIC 37, Transportation Equipment. It has very similar numbers compared to Industry machinery and equipment.
  - However, SIC 3728 has nearly twice the LWDI's compared to relatively light manufacturers such as those making electronic equipment as shown in Table 7.

**Table 7. Nonfatal Occupational Injury And Illness Incidence Rates Per 100 Full-Time Workers, By Industry, 1998**

Industry	Injuries & Illness			Injuries	
	SIC	Total Cases	LWDI*	Total Cases	LWDI*
Aircraft Parts and Equip.	3728	10.0	5.0	8.6	4.2
Ind. Machinery & Equip.	3500	9.5	4.0	8.7	3.6
Electronic And Other Electric Equipment	3600	5.9	2.8	4.8	2.3
Transportation Equip.	3700	14.6	6.6	11.2	5.3

Source: OSHA

\*LWDI = Lost Work Day Incident

- From October 1997 to September 1998, there were only 18 OSHA inspections of aircraft parts and auxiliary equipment manufacturing facilities.
- Table 7 indicates that nearly 55% of total fines are received by only five OSHA standards (out of over 32 total).

**Table 8. Standards Cited by Federal OSHA from October 1997 to September 1998 for SIC 3728, Aircraft Parts and Equipment, nec**

Standards	Description	Cited	# Insp	\$Fine
1910.1200	Hazard Communication	12	6	1,787
1910.0147	Haz.Lockout / Tagout	9	6	4,630
1910.0134	Respiratory Protection	6	4	1,800
1910.0212	Machines, gen. Requir.	5	4	4,150
1910.0132	Personal Protective Eq.	4	3	13,112
Subtotals		38	23	25,479
<b>Total <u>All</u> Standards Violations</b>		<b>83</b>	<b>18</b>	<b>\$46,802</b>

Source: OSHA

- ♦ ANSI Committee Z-365 issued a document entitled, *Control of Cumulative Trauma Disorders* (CTD) - Working Draft, in June 1997, for public review and comment.
  - Review of this document shows that a program-based approach with an emphasis on the following core elements will be recommended: Management Responsibility, Training, Employee Involvement, Surveillance (identifying problem jobs), Evaluation and Management of CTD Cases, Job Analysis and Job Design and Intervention.

## National Energy Consumption Patterns

This industry spends roughly \$200 million annually on energy.

Total energy consumption increased a total of only 1.5% from 1991 to 1996 for SIC 37 (Transportation Equipment).

- ♦ Table 9 indicates natural gas energy consumption is higher than electricity for SIC 37.

**Table 9. SIC 37 Total Energy Consumption 358 Trillion BTU (1994)**

<b>Natural Gas</b>	<b>43%</b>
<b>Electricity</b>	<b>37%</b>
<b>Coal</b>	<b>8%</b>
<b>Other (Fuel Oil etc.)</b>	<b>12%</b>

*Source: DOE Energy Information Administration*

## Typical Electricity Requirements

In 1996, the \$17.3 billion aircraft parts and equipment industry purchased 3.5 billion kWh of electricity at a cost of \$195.5 million.

- ♦ Within SIC 3728, even though the quantity of electricity used is slightly less than that of gas, electricity accounts for approximately 80% of total purchased energy costs.
- ♦ Total energy costs are about 1% of shipment revenues.

The aircraft parts and equipment industry segment is more energy intensive than typical assembly operations. It is equally energy intensive (but not as capital intensive) as most traditional manufacturing industries (see Table 11)

- ♦ The ratio of electricity consumption per dollar of value added for SIC 3728 is higher than that for automotive assembly operations (SIC 3711), and slightly lower than that for the manufacturer of vehicle parts (SIC 3714).
- ♦ The ratio of machinery/equipment assets per dollar of value added for SIC 3728 is similar to that found in automotive assembly operations, but much lower than that in vehicle parts manufacturing.

**Table 10. Intensity of Electricity Consumption and Capital Investment**

Industry SIC Code	1996 Value Added (\$, Million)	Electricity Purchased (kWh, Million)	kWh/ VA	Mach./Equip. Assets (1992) (\$, Million)	Mach. & Eq. Assets/ \$ VA
3728	\$11,046.7	3,526.3	0.32	6,215.2	0.49
3711	\$55,369.1	9,737.4	0.18	\$21,095.9	0.47
3714	\$44,209.9	15,559.4	0.35	\$26,709.4	0.86

Source: Census Data

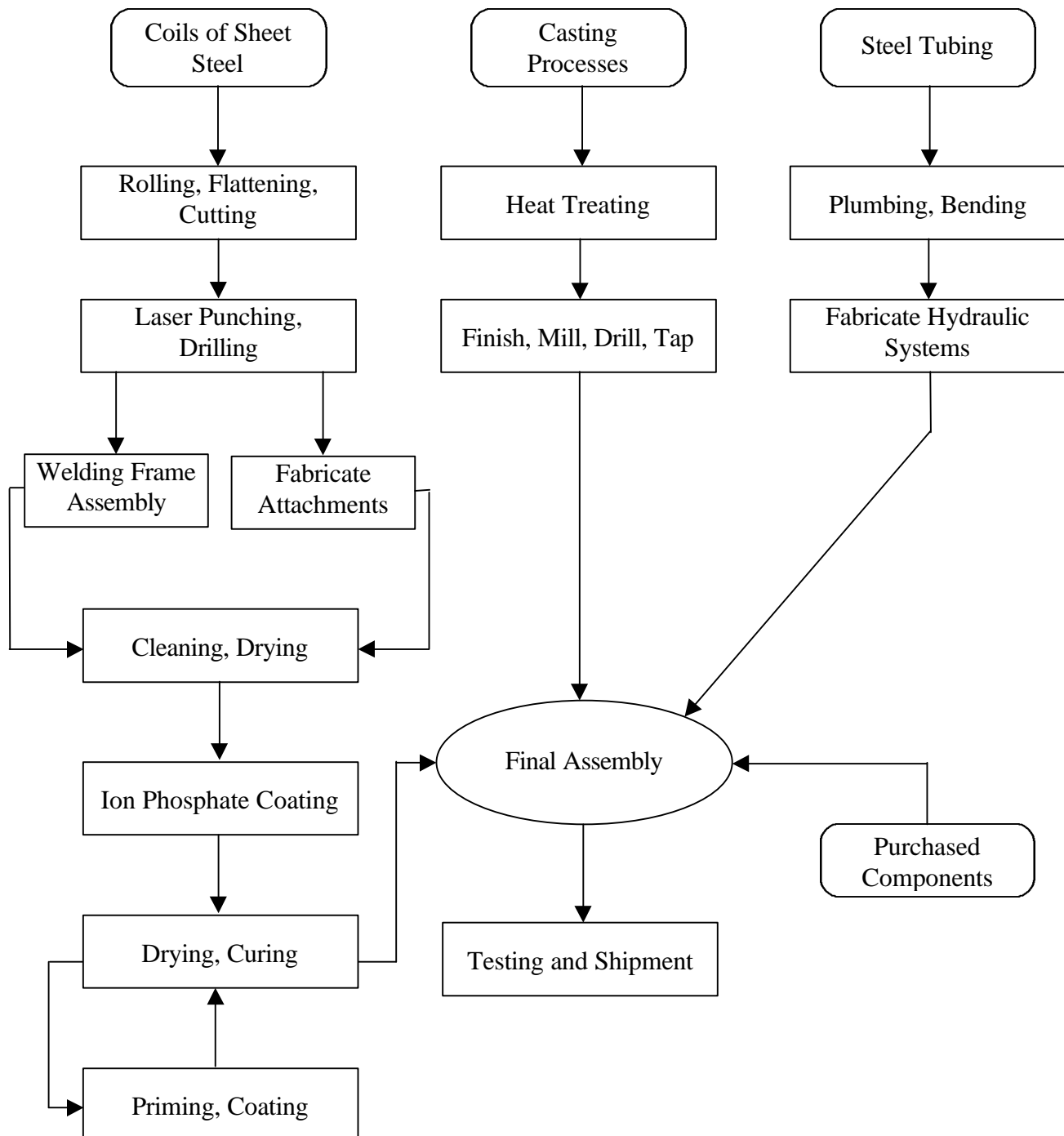
Table 11 indicates that almost 40% of electricity end-use kWh for SIC 37 is by Machine Drive solely.

**Table 11. SIC 37 Major Electricity End-Uses (1994)**

Machine Drive	39.5%
HVAC	18.0%
Facility Lighting	16.5%
Process Heating	9.0%
Facility Support, Other	17.0%

*Source: DOE Energy Information Administration*

**Figure 2. Typical Process Flow Chart**



## Manufacturing Process Issues

### Processes Overview

The manufacture of aircraft parts and auxiliary equipment encompasses a wide variety of manufacturing processes. The common links between the production of diverse components such as landing gear, brakes, hydraulic systems and electronic systems include the high quality aerospace specifications and the rigorous standards to insure that these quality measures are being met.

- ♦ The risk of substantial liability requires documentation by all manufacturers for every stage of the production process.
- ♦ Modifications within the manufacturing process undergo rigorous testing before incorporation into the production cycle.
- ♦ Aluminum, titanium and other high strength to weight metals and their alloys are used in the production of aircraft components.
- ♦ Computer aided design software and finite element analysis are used to optimize part design to meet strength and weight requirements.

Typical processes for the production of aircraft parts include casting, forging, stamping, joining processes (brazing, TiG and MiG welding), heat treating and various assembly processes.

- ♦ There are large numbers of shaping and non-shaping processes, the most energy intensive of which are casting/molding, metal deformation, and surface finishing.
- ♦ Investment casting processes are used in the production of complex parts containing holes and internal cavities. The casting process steps are as follows:
  - A pattern is made in wax as a model of the component. The mold material, commonly a ceramic, is formed around the wax model. The assembly is heated above the melting point of the wax and the wax is poured out. The mold is heated to a high temperature to burn out the last traces of the wax and to harden the mold material.
  - Excellent standards of surface finish and dimensional control can be achieved.
- ♦ Sand casting processes are used in the production of less complex parts where surface finish is not critical, or subsequent machining operations will be performed.
  - Sand is compacted around the pattern of the object to be made.
  - A higher percentage of refractory-base materials and other binding materials are used in the more advanced casting methods.
  - A metal charge is combined with other alloying additives and fed into a furnace (usually an electric arc, an electric induction, or a gas fired cupola furnace).

- The conditions for pouring the metal into the mold are tightly controlled to minimize voids and to insure process repeatability.
- ♦ Special heat treating cycles, surface finishes and coatings are necessary to protect components from the difficult environmental conditions typical of the aircraft industry.
  - Shot peening is used to treat many components that are designed to operate in high fatigue environments.
  - Heat treating cycles are designed to balance hardness and strength. Selective heat treating is typically used to surface harden or case harden components that need to also maintain a ductile core. Hard, brittle materials that have been through hardened will likely not survive the fatigue cycling typical of aircraft components.
  - Electroplated aluminum, titanium nitride and other advanced coatings/finishes are designed to match lubricity and corrosion resistance requirements within a wide range of temperature and humidity conditions.
- ♦ Sheet metal forming operations are similar to those in other metal fabrication industries, but tolerances need to be met and have surface finishes as called out by aerospace specifications are required.
- ♦ Various forging processes are used depending on the strength requirements and complexity of the part.
  - Typical tensile strengths of *forged* aluminum can reach 100,000 psi, compared to 50,000 psi for *cast* aluminum parts.
  - Steam or compressed air is used to drive the forging hammers and presses.
- ♦ Machining operations include an extensive array of special dies, tools, and machine tool accessories.
  - Improvements in high speed spindles and servocontrol technology now require less riveting hours and more metal machining hours, and with this, more machine tools will be required.
- ♦ Finishing processes include anodizing, liquid coating, powder coating electroplating and other plating processes.
- ♦ Components to be powder coated are cleaned and submerged in a large electrostatically charged paint tank.
  - Electric infrared, gas infrared or gas convection heating is used to cure the powder coating.
  - A temperature of 360°F (182°C) must be achieved to dry and cure the paint.

## Process Experiences

Boeing experienced production problems in 1997 when it attempted to double its production capacity.

- ♦ Production bottlenecks caused by labor and parts shortage as well as antiquated production systems forced the company to build its airplanes out of sequence, dramatically boosting production costs.

Boeing developed the Aircraft Creation Process Strategy (ACPS) in 1998 to build multiple models of aircraft on a single production line.

- ♦ The objective was to produce aircraft that would be flyable almost immediately upon leaving the factory. After preliminary flight checks, they would be delivered “green” to a worldwide network of “last –stage customization” centers for interiors and paint application. No major structural modifications or reconfigurations would be performed.
- ♦ Other manufacturing advances included increased reliance on sophisticated software to provide consistent, detailed designs. Computer-generated systems relying on “knowledge-based” product definition and engineering were incorporated into aircraft parts suppliers' manufacturing processes.
- ♦ Aircraft final integration would take place at one factory position, relying on prestuffed, modular components, the larger ones arriving on air-bearing dollies.
- ♦ Advantages of one-spot final assembly include buildings that only need to be wide enough to rotate wings during installation, with a minimum high-bay area required.

## Technology Trends

As economic pressures force operators to continue flying aircraft well beyond their original design lives, the aging of both civil and military aircraft is becoming of increasing concern. The aviation industry and government agencies are looking to develop technologies, methods, and procedures to ensure the continued airworthiness of these aircraft at a reasonable cost.

- ♦ Future materials and processes will require greater integration with design, manufacturing, survivability, and logistics. The response for these challenges comes from advances in the areas of casting technology, nondestructive evaluation and composite materials fabrication.

Advances in casting technology reduce costs by consolidating subcomponents. For example, complex and manufacturing intensive multi-piece parts in secondary structures are being replaced with castings that will reduce part counts, joint materials, labor and weight.

- ♦ Thick investment-cast parts weighing up to 400 pounds have been commercially produced.
- ♦ Titanium castings are being welded on newly developed military aircraft, replacing fasteners and adhesives.
- ♦ However, several critical issues must still be addressed before casting technology can be more widely implemented.
  - Establishment of criteria for nondestructive inspection (NDI) of thick sections and shell mold inclusions.
  - The effects of flaws on fatigue performance.
  - The development of heat treatment standards.
  - The lack of specifications.
- ♦ Another major issue for substitution of castings in aging systems is a requirement for qualification testing. No clear guidelines are available to decide whether lengthy qualification tests should be required for the substitution of every part.

Semi-Solid Forming (SSF) will replace casting technologies for selected aerospace parts.

- ♦ SSF consists of rheocasting, reheating, and forming.
  - Rheocasting uses magneto-hydrodynamic stirring to yield nondendritic (thixotropic) microstructures.
  - An induction furnace is used to reheat the thixotropic billet.
  - The mold is filled with the semi-solid material to produce the finished part.

Periodic and accurate nondestructive testing is critical to extending the life of aircraft equipment.

- ♦ Advanced nondestructive inspection and testing (NDI/T) techniques are used for determining material properties such as fatigue, corrosion, and cracking. Thermography, magneto-optic imaging (MOI), and automated ultrasonic scanning are some examples of these techniques. The flexibility, reliability, and sensitivity of each technology varies because of inherent limitations as well as the degree of their development.
- ♦ Automated scanning and MOI have been extensively developed and currently constitute rugged and easy-to-operate systems. Thermography has been around for some time, but only recently has the infrared camera sensitivity and computing power become available and affordable. A hand-held thermographic system is currently being developed for the detection of corrosion in metallic structures, and initial performance is very promising.
- ♦ Another technology under development is that of “meandering winding magnetometer” (MWM) array. This is a new surface mountable eddy-current sensor array that can monitor early stage fatigue damage, crack initiation, and crack growth. MWM is suitable for monitoring on-line fatigue tests of coupons and complex components, as well as difficult-to-access locations on aircraft.

Composite fabrication processes such as fiber placement and resin transfer molding (RTM) have proven that automated systems can reduce the cost of lay-up, fabricate complex shaped parts, improve reproducibility, and minimize material waste.

- ♦ Advanced processes such as fiber steering, resin film infusion, and vacuum assisted RTM will provide a means to fabricate affordable aircraft in the 21<sup>st</sup> century. Automated fiber placement has already proven to be an affordable method for manufacturing a wide range of parts with complex surface geometry, thick cross sections, and large unitized structures.
- ♦ Advances in machine control and head design are reducing manufacturing costs. This technology will allow cost-effective unitized structures, which impact affordability through reduced part count, elimination of fasteners and reduced hand labor.
- ♦ Resin transfer molding and related processes, in which resins are infused into dry fiber preforms, also have great potential. They enable complex shapes and a high degree of surface definition, providing affordable alternatives to hand lay-up, casting and machining.

Core materials have great potential to impact affordability. The most efficient type of aircraft structure is composed of stiff skins separated by a lightweight core material.

- ♦ Honeycomb core materials made of graphite or aramid fibers have the potential to meet structural requirements and to survive in a corrosive environment. In addition, syntactic materials consisting of micro-ballons in a resin also provide potential for affordable lightweight aircraft parts. Further long term evaluation and testing is required.

Corrosion costs military aviation over \$3 billion annually in maintenance and repairs. Efforts to extend the service life of aging aircraft require a new criterion for materials and structures performance beyond the design limit.

- ♦ The Navy has developed corrosivity monitoring sensors (CMS) that measure the extent of corrosion of structural metals. The CMS permits the measurement of corrosivity of environments in open, enclosed, and inaccessible hidden structures. CMS systems can also measure the permeation of moisture and corrosive gases through barrier materials such as sealant, coatings and paint.
- ♦ Primer Systems: Primers normally contain high concentrations of corrosion inhibitors such as chromates, and are designed to provide superior adhesion and corrosion protection. Polyurethane topcoats are formulated to enhance corrosion protection and durability. Other technologies have recently been introduced, such as non-hexavalent chromate pretreatments, self priming topcoats, flexible primers, low volatile-organic-compound (VOC) coatings, temporary and multi-functional coatings.
- ♦ Surface pretreatments: One of the main thrusts in the pretreatment area is the total elimination of hexavalent chromium because of environmental regulations.
  - Chromate conversion coatings (CCC) chemically form a surface oxide film (typically 40 to 60 mg/ft<sup>2</sup>) to enhance the overall adhesion and corrosion prevention properties of the protective finishing system applied over them.
  - Three categories of CCC alternatives have been studied in the Navy: inorganic non-chromated solutions, chromium (III) based treatments, and sol-gel formulations.
- ♦ Polyurethane topcoats: Aliphatic polyurethane coatings are ideal for applications where it is necessary to have superior weather and chemical resistance, durability and flexibility.
  - An alternative topcoat technology that allows for direct substrate coating is the self-priming topcoat (SPT). The SPT is a VOC-compliant, non-lead, non chromium high solids polyurethane coating that was designed to replace the current primer and topcoat paint system. The two main advantages to this coating are the reduction of steps in the finishing process, and the elimination of hazardous emissions and toxic wastes.
  - A water-borne polyurethane topcoat , which virtually eliminates VOCs, is an environmentally friendly replacement for the high-solids polyurethane aircraft topcoat. Successful implementation will eliminate the need for expensive pollution abatement equipment while maintaining the high performance properties of standard aerospace topcoats.
- ♦ Thermal spray technology: HVOF-sprayed materials are highly wear resistant, and have excellent adhesion. They are typically metallic-ceramic compounds such as tungsten carbide-cobalt.
  - HVOF technology has been used in many industrial applications for many years under various trade names. HVOF in aircraft has been limited mostly to wear surfaces on turbine engine components. Transition of this technology to other sliding contact, wear surfaces is expected.
  - Initial testing shows potential increases in service life of two or two and a half times that of chrome plating, full compliance with OSHA and EPA permissible exposure

- limits, significant reductions in component processing time for coating application, and no hydrogen embrittlement potential.
- The Department of Defense projects to fully qualify HVOF coatings for landing gear, hydraulic actuators, propeller hubs, helicopter dynamic rotor components, and gas turbine engine components.
  - ♦ Adhesive films: Flexible films bonded to painted surfaces provide a durable, weather-resistant finish when applied over standard corrosion-resistant primers. The films can be formulated from polyester, polyurethane or fluorocarbon resins with acrylic or other adhesives. Initial demonstrations have shown good results with no safety or environmental hazards.
  - ♦ Electrodeposition and powder: Electrodeposition (E-coat) and powder coatings are also being applied to aircraft parts.
  - ♦ Corrosion prevention compounds have been reformulated to replace CFCs and eliminate the ozone-depleting issue.

New alloys are being produced. AerMet 310 is an alloy that has a strength-to-density ratio greater than that of most titanium-based alloys. This new material is considered for landing gear and other critical aircraft components where high strength is required in combination with smaller size and/or lighter weight.

- ♦ While AerMet 310 is offered for the next generation aircraft landing gear and hardware, its unique combination of properties makes it a logical candidate for tooling and any other parts or components that might benefit from higher strength, smaller size, and lower density.

High Velocity Manufacturing (HVM) technology combines very high machine acceleration/deceleration and ultra-fast spindle speeds to make possible the manufacture of simpler, lighter, and more accurate monolithic parts.

- ♦ High-force linear motors replace mechanical axis-drive systems like ballscrews and rack and pinions. It marks the beginning of a new era for faster, less expensive production of lighter, stronger, large aircraft structural components.

New software verifies the programs for cutting the tooling before it is sent to the machine control, making it possible to manufacture parts without a single dry run or prove-out that will fit correctly with its mating parts on the assembly line.

- ♦ Close tolerance contoured surfaces are inspected and compared to the customer's quality specifications prior to any chip cutting.

The increased use of cryogenic thermal treatments to enhance material properties.

- ♦ Cryogenic processing increases wear resistance, dimensional stability and hardness particularly for steels.
  - Eliminates the possibility of spontaneous transformation of retained austenite to martensite in the steel part during fabrication or in service.

- The formation of fine eta carbides within the metal microstructure has been correlated to significant improvements in material properties.
- ♦ The most successful, consistent applications of cryogenic processing are incorporated directly into the heat treating process, after austenitizing but before the first temper.
- ♦ Many of the published applications involve the improvement in performance of tool steels.

Advanced vertical machining centers offer productivity improvements by their ability to run at higher rpm for longer periods of time and the ability to maintain speed during bigger and deeper cuts.

- ♦ The programmers use the latest CAD/CAM software to do dry runs to check for toolpaths and see the part being machined on the control panel screen without actually running the part. It is then possible to make changes, proof the part, archive the program and run the job directly from the computer station.

## Environmental Regulations and Issues

Federal, state and local statutes and regulations relating to the protection of the environment and the health and safety of employees and other individuals have resulted in higher operating costs and capital investments by the industry

Airlines will continue to retrofit older airplanes to meet FAA Stage III noise regulations and to comply with stricter safety guidelines.

The industry is generator of both hazardous and non-hazardous wastes, which the treatment, storage, transportation and disposal are subject to various laws and governmental regulations.

According to the "Industry Reporting to the Toxics Release Inventory", on-and off-site releases, the transportation equipment industry reported the third largest decrease (55%) from 1995 to 1997.

- ♦ TRI releases dropped from 215.0 million pounds to 96.8 million pounds.

Both military and commercial aviation industries struggle to eliminate cadmium platings to comply with governmental regulations. Suppliers are looking to electroplated aluminum and other alternatives to cadmium for fasteners, electrical connectors, and avionics components.

Until recently, chromates were virtually the sole source for active corrosion inhibition in aircraft coatings. However, carcinogenic chromate-containing materials are becoming severely restricted, and significant efforts are underway to develop nontoxic inhibited primers.

In the area of surface pretreatments, one of the main thrusts is the total elimination of hexavalent chromium, because of environmental regulations.

The application of topcoats can lead to the release of Volatile Organic Compounds (VOCs).

- ♦ VOC compliant, non-chromium high-solids polyurethane topcoats were designed to replace the current primer and topcoat paint system on aircraft. These coatings minimize hazardous emissions and toxic wastes.
- ♦ Water-borne polyurethane topcoats are also available and virtually eliminate VOCs.
- ♦ Another approach to avoiding VOCs from painting operations involves replacing the topcoat altogether, with adhesive applique films that present no safety or environmental hazards.
- ♦ Electrodeposition (E-coat) and powder coatings use waterborne coatings and keep VOCs to a minimum.

Corrosion prevention compounds have been applied less frequently since the early 90s due to environmental concerns. Corrosion preventives previously contained chlorofluorocarbons (CFCs) and petroleum solvents. It is well known today that CFCs are ozone-depleting substances, and the

petroleum solvents at the time were classified as Volatile Organic Compounds and also listed as Hazardous Air Pollutants.

A Thermal spray technology - High velocity oxy fuel (HVOF) has been tested to demonstrate if it is a beneficial alternative to conventional hard chrome plating. Initial testing shows full compliance with OSHA and EPA permissible exposure limits.

The EPA tracks emissions through a Toxic Release Inventory report according to whether pollutants are released in air, water, or in solid form.

- ♦ On-site and off-site total releases in pounds are reported by SIC codes.
  - Air emissions are further classified according to whether they are nonpoint (fugitive) or point (stack) emissions.
  - Water releases are either surface water or underground injection to wells.
  - Land releases are either on-site landfill or hauled away to other sites.
- ♦ The transportation equipment sector (SIC 37) is a minor Toxics Release Inventory (TRI) offender compared to other sectors. The chemical industry (SIC 28) reported 797.4 million pounds, or 30.9%, of on-site and off-site releases in 1997.
  - Primary metals (SIC 33) reported 694.6 million pounds, or 27%, and pulp and paper (SIC 26) reported 228.8 million pounds totaling 9.1%.
  - The transportation equipment sector (SIC 37) reported 96.8 million pounds, or 4% of total releases for the manufacturing SIC's 20-39.

Table 13 shows the operation and activities involved in the manufacture of aircraft parts and equipment and its environmental aspects and potential impacts:

**Table 12. Metal Processing and Environmental Impacts**

<b>Activities and Potential Environmental Impacts</b>		
<b>Operation</b>	<b>Activities</b>	<b>Environmental Aspects and Potential Impacts</b>
Chemical Milling Maskant Application and Chemical Milling	Use and disposal of maskants containing either toluene/xylene mixture or perchloroethylene	Air pollution from organic HAP emissions, waste maskant
Metal Finishing	Use and disposal of processing solutions, cyanide, heavy metal baths	Air pollution from HAP emissions; Contaminated wastewater including cyanide solutions, corrosive acid and alkali solutions; heavy metal sludges
Coating Application	Primer and topcoats application and disposal	Air pollution from organic HAP emissions; waste paint; waste solvent thinner

#### Chemical Milling Maskant Application and Chemical Milling:

- ◆ This operation uses etchant solutions to reduce the thickness of selected areas of metal parts in order to reduce weight.
- ◆ Chemical milling maskants are typically rubber or polymeric-based coatings applied to an entire part or subassembly by brushing, dipping, spraying, or flow coating.
- ◆ After the chemical milling maskant is cured, it is removed from selected areas of the part where metal is to be removed during the chemical milling process
- ◆ Chemical milling maskants typically contain either a toluene/xylene mixture or perchloroethylene as solvent constituents. These chemical solvents vaporize when exposed to air, and if not stored in tightly sealed containers become a source of hazardous air pollutants (HAPs). These organic HAP emissions also occur as the solvent evaporates as the chemical milling maskant is applied and cured.

#### Metal finishing:

- ◆ Metal Finishing processes are used to prepare the surface of a part for better adhesion, improved surface hardness, and improved corrosion resistance.
- ◆ Typical metal finishing operations include chemical conversion coating, anodizing, electroplating, and any operation that chemically affects the surface layer of a part.
- ◆ Each of these metal finishing operations has the potential to significantly impact the environment by discharging metals, cyanides, phosphates, acids, and other contaminants to waterways, soil, or groundwater.
- ◆ HAP emissions and contaminated wastewater are the most significant environmental aspects of metal finishing operations. As the organic chemicals in the processing solutions evaporate, they generate hazardous vapors and emissions. Evaporation of solution also occurs from refurbished parts as they are removed from the processing tanks.
- ◆ Wastewater from these operations includes cyanide solutions, corrosive acid, and alkali solutions

#### Coating Application:

- ◆ A coating is a material that is applied to the surface of a part to form a decorative or functional solid film. The most common coatings are primers and topcoats
- ◆ Coatings are applied to aircraft components using several methods of application. The methods most commonly used are spraying, brushing, rolling, flow coating, and dipping. Nearly all coatings contain a mixture of organic solvent.
- ◆ Organic HAP emissions from coating application are generated from evaporation of solvents during mixing, application, and from overspray, which is exhausted from spray booths or hangars
- ◆ Coating operations also produce waste paint and waste solvent thinner that are typically drummed and shipped offsite as RCRA hazardous waste

Parts cleaning has been significantly impacted by government regulations such as:

- ♦ EPA's National Emission Standards for Hazardous Pollutants (NESHAP),
- ♦ EPA's Significant New Alternatives Policy (SNAP), enacted in March of 1994,
- ♦ The 1987 Montreal Protocol, and more recently
- ♦ The Metal Products and Machinery (MP&M) standard, whose guidelines were published in April 1995, and sent out for comment regarding discharge of cleaning effluent to Publicly Owned Water Treatment (POWT).
- ♦ Aqueous cleaning has been steadily replacing solvent-based systems.
  - Aqueous systems have a mechanical focus on anything that breaks the bond between the soil and the part.
  - Aqueous mechanical agitation methods include high-pressure spraying, part rotation and ultrasonic cavitation in a variety of techniques.
  - Aqueous cleaning systems require heated drying techniques such as evaporative hot air or non-evaporative high-velocity air blowoff to prevent rust, corrosion or spotting on workpieces.
- ♦ Neutral pH, aqueous-based degreasers are typically used for the removal of light soils, specifically light oils which include cutting, shearing, honing and machining oils.
- ♦ There are certain applications involving heavy oils and greases, and/or heavy soil loads that require a much more aggressive chemical approach such as caustic cleaners.

The handling and disposal of metal removal fluids (MRFs) is increasingly becoming another environmental issue that machining operations such as those found in SIC 3728 have to confront. New NIOSH and OSHA regulations are being proposed which lower the allowable concentrations of bacteria in MRF's by a factor of 10.

- ♦ UV based systems are commercially available for the destruction of bacteria found in MRF's without the use of biocides such as chlorine.

## Opportunities for Increased Electricity Use

Induction melting.

Induction heating for selective heat treating of components.

Electrocoating to improve finish quality and corrosion resistance on aircraft equipment components.

- ♦ Epoxy resins are delivered via a water slurry, and therefore do not require an additional gas convection dry-off oven to dry the part prior to coating.
- ♦ Coating processes eliminate solvents to improve environmental sensitivity.

Induction heating for the reheating phase of semi-solid forming (SSF) metal processing.

Aqueous cleaning, which replaces solvent based cleaning, requires various heaters for drying parts after washing.

Infrared curing for powder coated parts.

Increased compressor load to produce liquid nitrogen for use in cryogenic processing.

Plasma arc cutting of metal (more economical than oxyfuel for thicknesses under 1”).

Laser cutting, drilling and punching for automating production operations.

Electrical discharge machining (EDM) for cutting shapes into thick or hardened steel is more economical than sawing or milling.

- ♦ Electric spark erodes metal in front of spooled wire or shaped plunger.
- ♦ Electrochemical machining process variation adds conductive fluid between shaped plunger and the part.

## Areas of Decreased Electricity Use

Energy efficient motors and drives.

Energy efficient shop lighting.

## Opportunities for Electric Utilities

Technology advances and business strategies need to fit with industry leaders Boeing and Airbus.

Utilities can provide increased awareness of electrotechnologies to enable aircraft parts manufacturers to replace coatings processes that are being penalized by environmental regulations.

Casting, forging and heat treating electrotechnologies minimize waste streams and can improve yield rates and quality of high value parts.

Most of the energy used in this industry is used for motors, heating, and lighting.

- ♦ Capital investment should target replacing worn out equipment with new technology.
  - High speed stamping machines.
  - Combination punching and laser cutting machines.

## Industry Associations and Periodicals

The following trade associations are resources for industry information and possible collaborative efforts.

### **Aerospace Industries Association of America**

1250 Eye St. NW  
Washington, DC 20005-3924  
Phone: (202) 383-2350  
[www.aia-aerospace.org](http://www.aia-aerospace.org)

### **American Institute of Aeronautics and Astronautics**

1801 Alexander Bell Drive  
Reston, VA 20191-4344  
Phone: (703) 264-7500  
[www.aiaa.org](http://www.aiaa.org)

### **US Census Bureau**

4700 Silver Hill Rd  
Suitland, MD 20746  
Phone: (202) 457-2000  
[www.census.gov](http://www.census.gov)

### **Air Transport Association**

1301 Pennsylvania Ave. NW  
Washington, DC 20004  
Phone: (202) 626-4000  
[www.air-transport.org](http://www.air-transport.org)

### **US Department of Transportation**

400 Seventh St. SW  
Washington, DC 20590  
Phone: (202) 366-4000  
[www.bts.gov](http://www.bts.gov)

The following trade publications are resources for industry information.

### **Aerospace Daily**

The Aviation Week Group  
1200 G Street NW, Suite 200  
Washington, DC 20005  
Phone: (202) 283-2350  
[www.awgnews.com](http://www.awgnews.com)

### **Advanced Materials & Processes**

9639 Kinsman Rd.  
Materials Park, OH 44073  
Phone: (440) 338-5151  
[www.asm-intl.org](http://www.asm-intl.org)

### **Aviation Weekly and Space Technology**

The McGraw-Hill Companies  
1200 G Street NW, Suite 922  
Washington, DC 20005  
Phone: (202) 283-2300  
[www.awgnet.com](http://www.awgnet.com)

### **Boeing Current Market Outlook**

Boeing Commercial Airplane Group  
PO Box 3707, MS 76-15  
Seattle, WA 98124-2207  
Phone: (206) 237-9167  
[www.boeing.com](http://www.boeing.com)

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